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Recent Advances in Metal-based Drugs in Cancer Therapy

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Abstract: The distinctive attributes of metals, for example, their redox activity, varied coordination modes, and reactivity against biomolecules have drawn a lot of attention to the therapeutic potential of metal complexes against various diseases. These characteristics make them a desirable probe for the development of metallodrugs that bind to the targeted biomolecules selectively and change the cellular mechanism of proliferation. Metal-based drugs have appeared as propitious candidates for cancer treatment attributable to their exceptional structural features and versatile modes of action. Recently, a substantial advancement has been made in the development of metal-based compounds with enhanced effectiveness and reduced toxicity profiles. Numerous metallodrugs have been assessed both *in vitro* and *in vivo*, with a few even progressing to clinical trials. Nevertheless, it is still challenging to find novel chemical formulations and therapeutic approaches that can specifically target cancer cells while sparing healthy cells. For many types of cancer, there are still few treatment choices available, despite advancements that have been directed to the design of novel therapeutics. This review article provides an outline of the up-to-date advancements in the field of metallodrugs for cancer treatment.

Introduction

Our body normally produces new cells to replace old and damaged ones as they become progressively dysfunctional. Occasionally, this regular process deviates, leading to the development of new cells when our body doesn't require them. Cancer is characterized by unchecked cell proliferation and undesired development of cells (Brown et al., 2023; Solairaja et al., 2023; Mehta et al., 2023; Kulkarni et al., 2023; Madhu et al., 2023; Madhu et al., 2024; Adhikari et al., 2024). Genetic damage to cells makes them unable to respond to normal tissue controls, which causes cancer (Bhattacharjee and Mukherjee, 2016; Bertram, 2000; Das et al., 2021; Boga et al., 2022; Thangavel et al., 2024). Most malignancies spread through the fast cell division of the afflicted tissue, resulting in tumors of different sizes (Bisoyi, 2022; Kesavan et al., 2023; Vashist et al., 2024; Das et al., 2024). With the death rate rising annually, cancer is gradually overtaking cardiovascular diseases as the second most important cause of death, accounting for around 25% of all fatalities worldwide (Siegel et al., 2023). The risk of most cancers is increased by a variety of factors, including environmental ones (vitamins and weight loss, tobacco consumption, certain infections, radiation exposure, lack of physical activities, obesity, and pollution) and internal/genetic ones (inherited mutations, hormones, and immune conditions) (Saini et al., 2020; Das et al., 2023; Nath et al., 2022). Genetic and environmental variables contribute around 5–10% and 90–95%, respectively, to the risk of most malignancies (Rashkin et al., 2020; Madhu et al., 2024). At some point during the human body's metabolic process, a variety of physiological and biochemical activities may also produce oxygen free radicals and other sensitive species as byproducts (Sinha

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et al., 2024). An excess of these free radicals can initiate oxidative damage to biomolecules (lipids, proteins, and DNA), which can eventually result in cancer and other chronic illnesses (Das et al., 2023; Nath et al., 2024). Since comprehension of the function of bioactive metal compounds and metalloproteins in the living system, tremendous progress has been achieved in the arena of bio-inorganic chemistry (Park et al., 2012; Adhikari et al., 2020). Modern drug discovery relies heavily on metal complexes (Adhikari et al., 2020; Singh et al., 2017; Bhattacharjee et al., 2022). Metal-based medications with promising pharmacological pertinence are being unveiled, thanks to the unique properties of transition metals (Park et al., 2012; Singh et al., 2018; Adhikari et al., 2020; Nath et al., 2024).

Pt(II) derivatives have garnered significant interest in the realm of anticancer medication research since the cytotoxic characteristics of cisplatin were discovered. M. Peyrone prepared cisplatin for the first time in 1845. B. Rosenberg and associates unintentionally found its anticancer activities in 1965 (Rosenberg et al., 1965). Because of its broad-spectrum effectiveness against numerous cancer types, including ovarian, cervix, testis, breast, bladder, rectum, colon, lung, head, and neck cancers, cisplatin is known as "the penicillin of cancer drugs" (Ghosh, 2019). It is among the top-selling anticancer medications worldwide after more than 50 years of use. However, cisplatin and its related compounds have also been shown to cause severe toxicity (Rabik and Dolan, 2007). Cisplatin mostly disrupts transcription and replication by creating intra- and inter-strand connections that warp the structure of double-helix DNA. Patients receiving cisplatin experience a variety of acute and chronic adverse effects, including nausea, vomiting, nephrotoxicity, ototoxicity, myelosuppression, etc. (Florea and Büsselberg, 2011). This is because platinum-based medications are non-selective and exhibit substantial general toxicity. The undesired side effects of cisplatin and many other platinum-based medications make it imperative for medicinal chemists to design and synthesise novel anticancer medicines that are exceedingly active, possess negligible toxicity, and exhibit selectivity (Oun et al., 2018). Therefore, efforts are being made to find and develop non-platinum metallodrugs that are both potent and safer.

Considerable anticancer activity was demonstrated by coordination complexes derived from metals, such as Cu, Ni, Pd, Ru, Au, Zn, Ir, etc. and biologically active ligands (Adhikari et al., 2024). The greater activity of metal complexes as compared to that of free ligands can be described by Tweedy's theory (1964), which states that the chelation process fundamentally decreases the polarity of the metal ion due to the fractional sharing of its (+ve) charge with the donor moieties and the potential for π electron delocalization in the entire chelation ring (Tweedy, 1964). The lipophilicity of the core atom is enhanced by the chelation ring, which facilitates its penetration through the lipid layer of the cell membrane. The high solubility, the size of the metal ion, and the existence of bioactive ligands of the studied complexes can also be used to explain their improved activity (Adhikari et al., 2025; Maity et al., 2025). Additionally, it has been discovered that when the bioactive ligand and the metal ions were coordinated, the anticancer potency improved (Debnath et al., 2025). The (+ve) charge of the metal ions enhanced the acidity of the coordinated ligand, leading to more powerful H-bonds with a (-ve) charge in the DNA of the malignant cells, which is why the metal chelates exhibit higher cytotoxicity (Simović et al., 2019).

History of metal-based anticancer drugs: Evolution from past to present

The therapeutic potential of certain metals and their compounds for the treatment of diseases has been utilized since the early days of civilization (Fricker, 2007). Metal-based compounds had an impact on modern medicine during the start of the 20th century when Erlich discovered the arsenic organometallic medication Salvarsan, which is used to cure syphilis. Antimony compounds were used to cure leishmaniasis, a parasitic disease, while gold cyanide was used to treat tuberculosis, another infectious disease (Navarro et al., 2010).

The interest in metal-based anticancer agents began with the discovery of the anticancer properties of cisplatin *cis*-[$Pt(NH_3)_2Cl_2$] in the 1960s (Rosenberg et al., 1965). Cisplatin was accidentally discovered to inhibit cell division in bacteria, leading to its investigation as a potential anticancer drug. Beginning with its first introduction in the 1970s, cisplatin has since gained widespread usage as one of the most active anticancer therapeutics for treating a variety of solid tumors, such as melanoma, lymphomas, testicular, ovarian, head and neck, bladder, and lung cancer. Cisplatin's effectiveness against testicular cancer was particularly dramatic. Before its introduction, cure rates were around 10%. With cisplatin-based treatment, those percentages shot up to an astounding 85%. The path of cisplatin wasn't without difficulties. Significant adverse effects of the medication include renal damage, hearing loss, nausea, and vomiting (Ghosh, 2019). However, the benefits often outweighed the drawbacks, especially in advanced cancers. By 1978, cisplatin's effectiveness and safety profile were well-established, leading to its approval by the US Food and

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Drug Administration (FDA). This encouraging tale solidified cisplatin's status as a ground-breaking medication. The effects of cisplatin go well beyond its intended application. It served as the basis for the design and synthesis of additional platinum-based medications, including oxaliplatin and carboplatin.

In the 1980s and 1990s, respectively, carboplatin and oxaliplatin (Fig. 1) were designed and approved to address some of the negative effects and resistance linked to cisplatin (Rixe et al., 1996). Although oxaliplatin is useful in treating cancers resistant to cisplatin and uses a distinct mechanism of action involving DNA cross-linking, carboplatin functions similarly to cisplatin but with less nephrotoxicity. Pharmacological applications of cisplatin and its derivatives (2nd generation carboplatin and 3rd generation oxaliplatin) are practiced globally for the treatment of cancer, while many other Pt-based analogs (nedaplatin, lobaplatin, and heptaplatin) are approved for cancer treatment in several nations (Tsvetkova and Ivanova, 2022). Clinical applications of Pt-based medications have also been hampered by the emergence of drug resistance, which result from acquired or innate numerous genetic and epigenetic modifications (Galluzzi et al., 2014).

Ruthenium-based anticancer drugs gained interest in rheumatoid arthritis, have also been investigated for their anticancer activities, particularly towards certain types of tumor cells resistant to other treatments (Mertens et al., 2023). Due to their stronger affinity for the thiol, sulfhydryl, and selenocysteine moieties of numerous protein targets and their weaker DNA-binding activity, Au-based derivatives with oxidation states of +I and +III have better selectivity and effectiveness against malignant cells than normal cells when compared to platinum-based complexes.

A number of transition metals, particularly the vital trace elements such as copper, are useful in the application of metallodrugs in anticancer treatments. Several copper-based complexes with ligands containing N, S, or O donor atoms exhibit strong anticancer activity and high cytotoxicity (Molinaro et al., 2020). Clinical trials are currently underway for numerous copper-based complexes: thiosemicarbazone-based Cu derivatives labeled with a radioactive isotope for positron emission tomography imaging of hypoxia (in neck and head tumors), several casiopeínas derivatives and elesclomol for leukemia, and Cu/disulfiram-based drug combinations for therapy and as diagnostic tools (metastatic breast tumor) (Krasnovskaya et al., 2020).

Among the most studied compounds for the design of

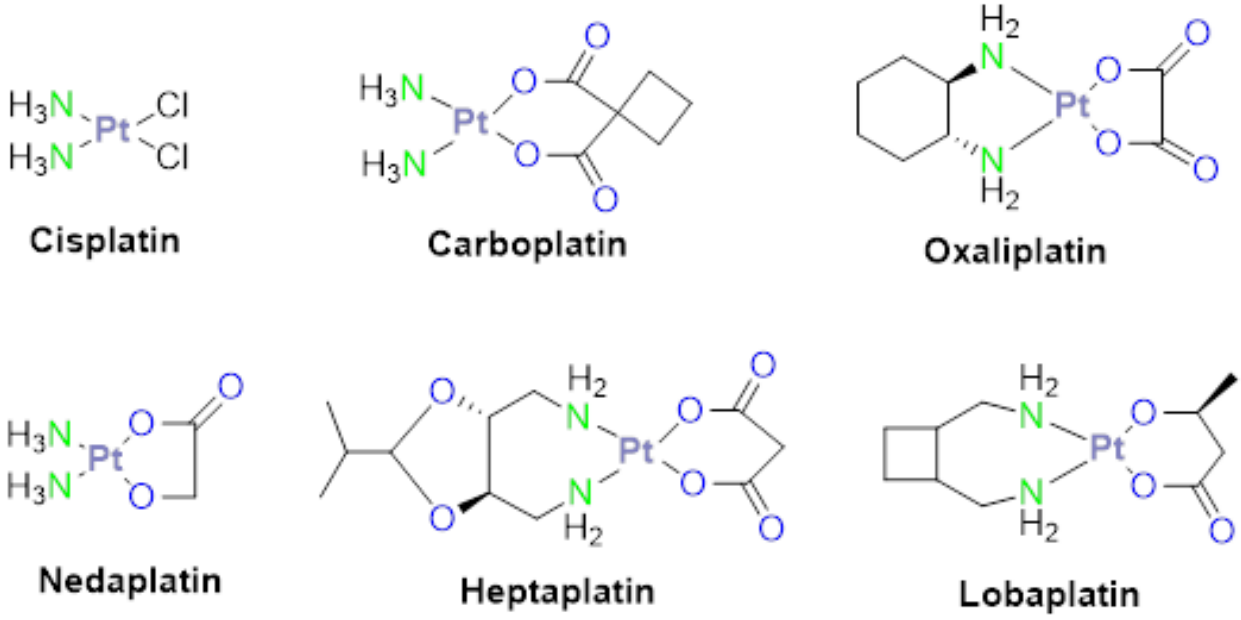

Figure 1. Clinically approved platinum-based anticancer drugs.

the late 20th century and early 21st century due to their potential to overcome cisplatin resistance and exhibit lower toxicity (Lee et al., 2020). Compounds like NAMI-A and KP1019 were developed and subjected to clinical trials; however, none of them have been approved for clinical application as of yet (Alessio and Messori, 2019).

Gold-based drugs, such as auranofin and aurothiomalate, originally prepared for treating anticancer drugs are Pd-based derivatives (Alam and Huq, 2016). Due to the comparable d^8-system of Pd(II) and Pt(II), structural analogues of Pt(II) complexes have been prepared, and their potential anticancer effects have been investigated (Abu-Surrah et al., 2008). Because the ligand exchange kinetics for Pd(II) derivatives are 10^5 times faster, those analogues do not exhibit activity similar to their promising Pt(II) counterparts. However, Pd(II)

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compounds behave differently than Pt(II) complexes, and the most promising candidates exhibit certain structural traits. Enhanced anticancer property was noticed for chelating ligands that are bulky and possess high lipophilicity (Alam and Huq, 2016).

It is well recognized that nickel, an important trace element for humans, animals, microbes, and plants, is a part of numerous enzymes and is vital for numerous metabolic processes. Furthermore, several nickel-based complexes have been designed, synthesised, and assessed for a wide range of bioactivities, including anticonvulsant, antimicrobial, antifungal, antioxidant, and anticancer properties (Li et al., 2020). Despite promising preclinical results, clinical development of nickel-based derivatives as anticancer agents has been limited due to their toxicity and side effects.

chemistry of mitochondrial respiration, elastin cross-linking, and iron absorption (Tapiero et al., 2003; Roy et al., 2023). Copper complexes have the potential to be effective anticancer agents among non-Pt drugs (Santini et al., 2014). The interaction characteristics of both copper and the ligand underpin the anticancer properties of copper-based complexes (Bhattacharjee et al., 2022; Roy et al., 2025). A few of the Cu-based compounds, for example, Cu(II)-elesclomol, casiopeina III, casiopeina II-gly etc., have entered the clinical trial because of the encouraging results observed in *in vivo* studies (Lucaciu et al., 2022). Our research group has investigated various supramolecular systems as part of our continuous efforts to explore their pharmacological and sensing properties (Ghosh and Adhikari, 2006; Adhikari et al., 2019; Adhikari et al., 2023). A series of Cu(II) binary ligand

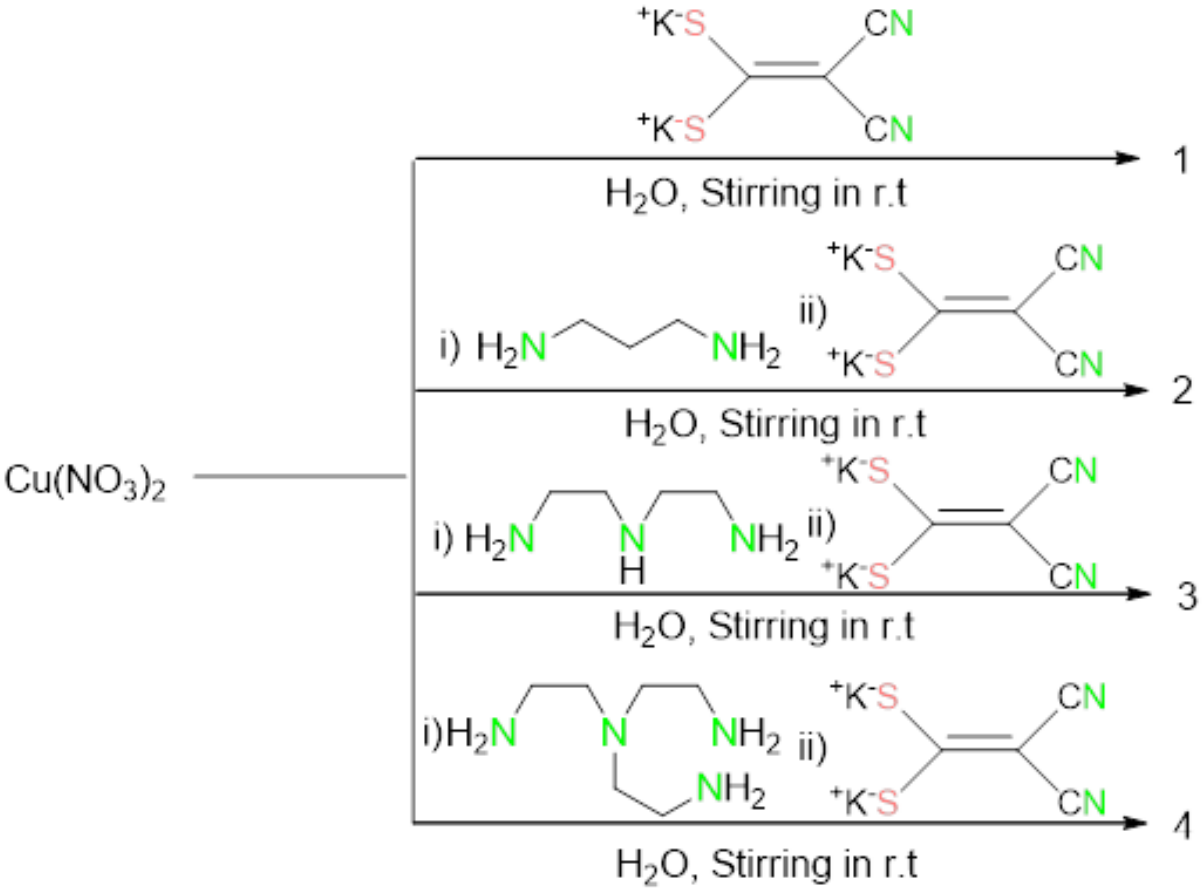

Figure 2. Synthesis of copper-based complexes (1-4).

Research continues to focus on the development of next-generation platinum and non-platinum-based compounds with improved efficacy and negligible side effects. The design of these drugs has been driven by the need to overcome the challenges of drug resistance and side effects associated with conventional chemotherapeutic agents.

Recent advances in non-platinum anticancer drugs

Copper plays an essential role in cell physiology as a free radical scavenger, a catalytic cofactor in the redox

derivatives (Fig. 2) with versatile 1,1-dicyanoethylene-2,2-dithiolate (*i-mnt*$^{-2}$) and polyamine ligands have been reported by Adhikari et al. (2019). The Cu(II) compounds displayed noteworthy anti-proliferative activities having IC_{50} in the significant micromolar range towards several human tumor cell lines, viz., lung H157, colon HCT-15, ovarian 2008, and cervical A431, all sensitive to cisplatin, and A431/Pt, which is resistant to cisplatin. The anti-proliferative activities barely correlated to the nature of the polyamine ligand. The [*Cu(imnt)*$_2$] (1) exhibited the most

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encouraging results with an IC_{50} value ≈ 2.1 μM against the five cancer cell lines examined. This value is over two times lower than that estimated for cisplatin. By using 3D cancer cell models, the growth inhibitory outcome of Cu complexes was more clearly demonstrated. The average IC_{50} values were found to be 3 to 7 times less than those of cisplatin. Cu(II) mixed-ligand complex (4) in particular has proved to be up to seven times as effective as cisplatin towards human non-small cell lung cancer cells H157 spheroids.

Several kinds of enzymes, including urease, carbon monoxide dehydrogenase, and hydrogenase, require nickel as a necessary component. Because of the cross-linking characteristics of nickel(II) with DNA and its resemblance with platinum(II), a number of nickel(II) compounds have demonstrated interesting catalytical properties and possible inhibitory effects towards different cancer cells (Ghosh et al., 2015; Adhikari et al., 2021). Supramolecular chemistry relies on numerous non-covalent contacts, for example, H-bonding, C–H…π, π…π, van der Waals forces, etc. (Ghosh and Adhikari 2006; Ghosh et al., 2011; Ghosh et al., 2008). Non-covalent forces exert substantial control over biological systems due to their specificity and lack of severity as compared to covalent forces (Ghosh and Adhikari, 2008; Ghosh et al., 2008; Adhikari et al., 2024). Bhattacharjee et al. delineated binary ligand Ni(II) complex *[Ni(2-ap)$_2$(i-mnt)]* (5) (Fig. 3) based on 1,1-dicyanoethylene-2,2-dithiolate (*i-mnt*$^{-2}$) and 2-amino pyridine (*2-ap*) ligands and explored the supramolecular properties and anticancer activities (Bhattacharjee et al., 2022). Single crystal X-ray study revealed that Ni^{+2} distorted square planar geometry and supramolecular assemblies have a leading impact on N − H···N hydrogen bonds. The anticancer study on metastatic colon cancer cells SW620 revealed a significant reduction in cell growth with increasing concentration of *[Ni(2-ap)$_2$(i-mnt)]* complex. A molecular docking investigation using Ni(II) complex *[Ni(2-ap)$_2$(i-mnt)]* and the APC protein verified the anticancer action outcomes found in the MTT assay. The Ni(II) complex effectively inhibited the migration and invasion of colorectal malignant cells *via* disrupting the APC-Asef interaction.

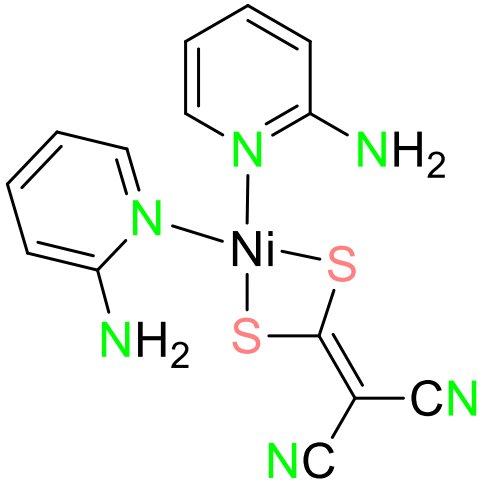

Figure 3. Molecular structure of Ni(II) complex [*Ni(2-ap)$_2$(i-mnt)*] (5).

Schiff bases and their metal complexes have demonstrated a wide range of biological activities (Kanmazalp et al., 2024; Adhikari et al., 2025). Bhattacharjee et al. recently reported the unsymmetrical pyridyl-based Ni(II) Schiff base compound 6 (Fig. 4) and its anticancer activities (Bhattacharjee et al., 2023). The Ni^{+2} adopts a distorted octahedral geometry, and weak C−H···π stacking interactions, C−H···O type intermolecular H-bonds, and π···π contribute to overall crystal stability. The anti-proliferative effects of the Ni(II) Schiff base compound were assessed towards HUH7, HCT116, A549 tumor cells, and Beas-2B normal lung cells. The Ni(II) Schiff base compound exhibited toxicity at high concentrations against Beas-2B cells. The Ni(II) Schiff base complex exhibited significant cytotoxicity against A549 lung cancer cells, exhibiting a lower IC_{50} value (24.85 μM) as compared to the Schiff base ligand. Incubation with IC_{50} dosage of Ni(II) Schiff base for 48 hours caused 45.73% apoptosis against HCT116 cells and 23.63% apoptosis against A549 cells. The investigation of the colony-forming assay indicated that at varying doses, both the Ni(II) Schiff base compound and the corresponding unsymmetrical pyridyl Schiff base influenced the rate of cell proliferation and growth. In fact, the Ni(II) Schiff base compound suppressed colonization in HUH7 and HCT116 cells more than the corresponding ligand. The Ni(II) Schiff base compound and the corresponding unsymmetrical pyridyl Schiff base ligand dramatically upregulated the expressions of p21 and p53 in HCT116 cells, indicating that both the compounds cause DNA damage and exert an impact on the cell cycle in HCT116 cells.

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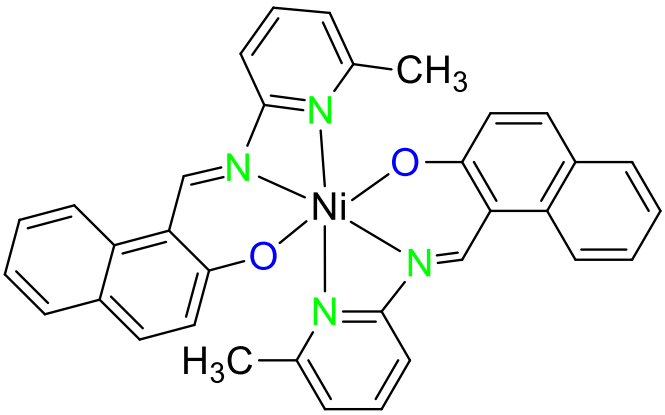

Figure 4. Molecular structure of pyridyl-based Ni(II) Schiff base compound 6.

Because of its structural and coordination chemistry related resemblances, palladium seems to be a good substitute for platinum in possible substitute anticancer drugs (Kapdi and Fairlamb, 2014). In the year 2017, Padeliporfin (TOOKAD®), a Pd(II)-substituted bacteriochlorophyll derivative, was the first Pd(II) compound permitted for clinical applications in photodynamic therapy for prostate cancer patients (TOOKAD). Adhikari et al. reported the synthesis and characterization of a new Pd(II) compound 7 (Fig. 5) derived from benzil bis(pyridyl hydrazone) ligand (Adhikari et al., 2023). A distorted square planar geometry was preferred by Pd^{+2}, according to single-crystal X-ray diffraction. The development of supramolecular assemblies in the solid-state structure of Pd(II) compound involved the contribution of C–H···π, intermolecular C–H···N, C–O···H, and π···π contacts. Strong hydrophilic interactions of Pd(II) complex with the polar part of the amino acids are confirmed by a molecular docking investigation. Using Dalton's lymphoma malignant cancer model, the anticancer properties of the Pd(II) compound and the corresponding ligand have been investigated both *in vitro* and *in vivo* (Adhikari et al., 2025). In DL cell line experiments, the Pd(II) complex exhibited a lower IC_{50} (22.01 μM) in comparison with the corresponding benzil bis(pyridyl hydrazone) ligand (180.71 μM). In mice, the Pd(II) compound exhibited concentration-dependent cytotoxicity and apoptosis, which decreased tumor volume, body weight, and cell viability. In contrast, the benzil bis(pyridyl hydrazone) ligand displayed no noteworthy effect on the surge in the lifetime of the mice.

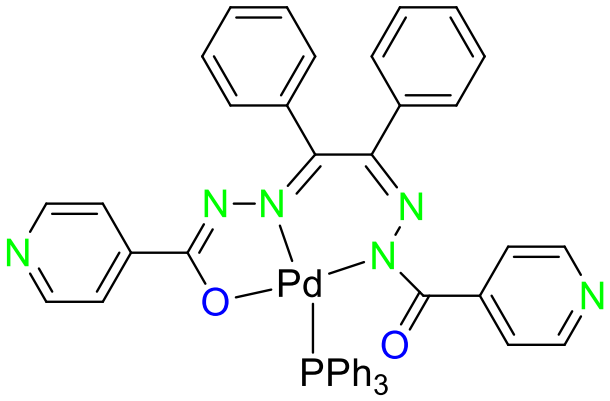

Figure 5. Molecular structure of Pd(II) compound 7 based on benzil bis(pyridyl hydrazone) ligand.

Coordination compounds based on zinc were known to possess anticonvulsant, antidiabetic, antibacterial, antioxidant, anticancer, and anti-Alzheimer's agent properties (Singh et al., 2014; Pellei et al., 2021). Zinc-based molecules have shown potential as photosensitizers in photodynamic therapy or as low-toxicity anticancer medications. Recently, our group reported a new zinc coordination complex 8 (Fig. 6) fabricated from nicotinohydrazide derivative ligand (Adhikari et al., 2024). Compound 8 exhibits a distorted octahedral ZnN_4O_2 coordination core. The *in vitro* antitumor activities studies of Zn(II) complex 8 against Dalton's lymphoma (DL) malignant cancer show that complex 8 reduced cell viability by inducing concentration-dependent cytotoxicity with a remarkable IC_{50} value of 10.36 μM. Furthermore *in vivo* studies of Zn(II) complex 8 with DL bearing mice model demonstrated that mice treated with complex 8 showed decreased tumor volume and body weight as well as a markedly longer lifespan, with a mean survival day of 23 days. With the ligand efficiency scores falling within the suggested limits for a hit, a molecular docking analysis demonstrated that the Zn(II) complex 8 may interact with mTNF effectively.

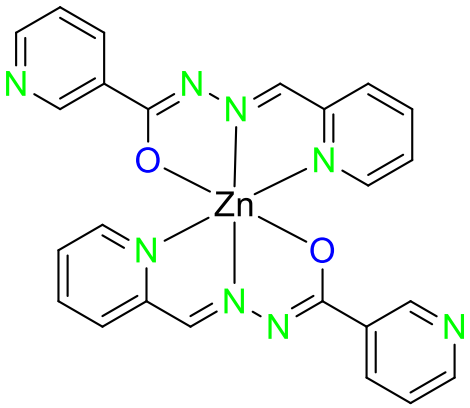

Figure 6. Molecular structure of Zn(II) complex (8).

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Our group also recently reported a novel non-polymeric and trigonal bipyramidal geometry Zn(II) complex [*Zn(tren)(i-mnt)*] (9) (Fig. 7) and explored anticancer properties against DL cancer cell lines (Bhattacharjee et al., 2024). On the DL cancer cell line, the Zn(II) complex 9 showed a substantial increase in cytotoxicity with an IC_{50} value of 12 µM. The Zn(II) complex demonstrated potent cytotoxicity, while the K_2*i-mn*t ligand showed no significant cytotoxicity. Molecular docking studies revealed that the complex has a higher binding affinity to 3DK8, suggesting stronger inhibition and interactions. These findings may aid in the development of targeted cancer therapies and enhance understanding of the zinc complex's cytotoxic mechanisms.

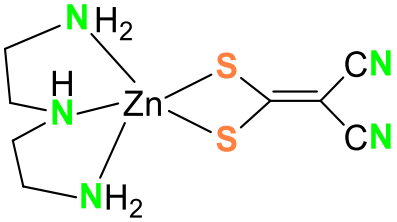

Figure 7. Molecular structure of Zn(II) complex [Zn(*tren)(i-mnt)*] (9).

Adenine, a purine nucleobase, is an ideal biologically related ligand for developing a broad range of topologically unique metallosupramolecular structures due to its unique molecular structure and well-endowed metal binding and H-bonding characteristics (Sen et al., 2024; Gupta et al., 2022; Bhattacharjee et al., 2025). Nath et al. (2025) recently reported a novel mononuclear Co(II) complex, [*Co(9-BuA)*$_2$*Cl*$_2$], (10) (Fig. 8) generated from 9-butyl adenine (9-BuA) building block and explored its anticancer properties. Crystal structure analysis revealed that the Co(II) ion in the complex is distorted in its tetrahedral environment. Both intramolecular and intermolecular hydrogen bonds support the formation of supramolecular assembly and stabilize the crystal structure. Cytotoxicity testing demonstrated the potential of complex 9 as a cytotoxic agent against DL malignant cancer cells (IC_{50} = 38 µM), and revealed a lower impact on normal PBMC cells. Molecular docking studies indicated that hydrophobic interactions between the Co(II) complex 10 and receptor residues stabilize the complex in an energy minimum state.

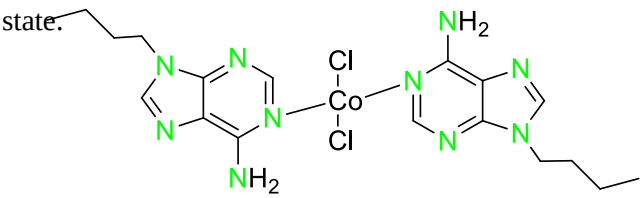

Figure 8. Molecular structure of Co(II) complex [*Co(9-BuA)*$_2$*Cl*$_2$] (10).

Future outlook and summary

The resurgence of metallodrugs in cancer therapy holds immense promise for the future. Although Pt-based drugs remain the most effective chemotherapeutic agents, novel strategies utilizing diverse transition metals are generating novel compounds for the treatment of cancer. It's encouraging to see that the field has clearly evolved over the past few years. Research now covers a wide range of contemporary topics, going well beyond the synthesis of novel chemicals and *in vitro* studies of their anticancer effects. Designing metal-based anticancer drugs that can solve the issues with clinically utilized medications while preserving their potency is gaining popularity. Future research should develop novel medications that increase tumor response for individual patients by focusing on medicines that are effective on a limited subset of cancers and target particular defects in these cancers.

The findings reviewed in this article indicate that the use of transition metals in conjunction with bioactive ligands demonstrated a highly effective alternative for designing anticancer therapeutics. Future investigations into the mechanisms of action or clinical trials should take this into account. The findings demonstrated that irrespective of the metal ion under investigation, coordination complexes nearly invariably boost the cytotoxic or antiproliferative action with reference to the ligand. This can be explained by the interaction of the complexes with the active sites, which enhances their lipophilicity, biocompatibility, and bioavailability, and allows them to pass *via* the lipid layer of the cell membrane to induce apoptosis. Enzymes, proteins, DNA, and hormones can all be targeted by metal-based compounds derived from bioactive ligands, which can disrupt the cell cycle and trigger apoptotic cell death through intrinsic or extrinsic pathways. Additionally, metal-based compounds can alter the redox balance by interactions with glutathione and NADH, or by producing ROS inside the cells. Furthermore, it is noteworthy to mention that several metal-based compounds have demonstrated sufficient potential to be effective against tumors resistant to cisplatin. It is understandable that metallodrugs for cancer therapy, both *in vitro* and *in vivo*, have received a lot of attention recently given their wide range of benefits. The primary requirement to turn the potential compounds into fully functional medications is extensive *in vivo* research on molecular mechanism, molecular stability, distribution profile, toxicity to healthy cells, etc.

In conclusion, metal-based drugs are poised to revolutionize cancer therapy. With continued research, we can expect the development of more potent, selective, and safer drugs, leading to improved patient outcomes and

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even potential cures for various cancers. However, challenges such as drug resistance, toxicity, and formulation optimization need to be addressed to fully realize the therapeutic benefits of metal-based drugs in clinical practice. While there is still much to be done, we hope that this article will be a useful informational resource, source of inspiration, or supplement for future research directions in the effort to find a cure for this "other pandemic," which is cancer.

Conflicts of interest

The authors declare no competing financial interest.

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